Exoskeletons for Human Performance Augmentation

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Exoskeletons for Human Performance Augmentation

Goal

Develop capabilities to increase human physical performance in combat environments
Speed, Strength and Endurance

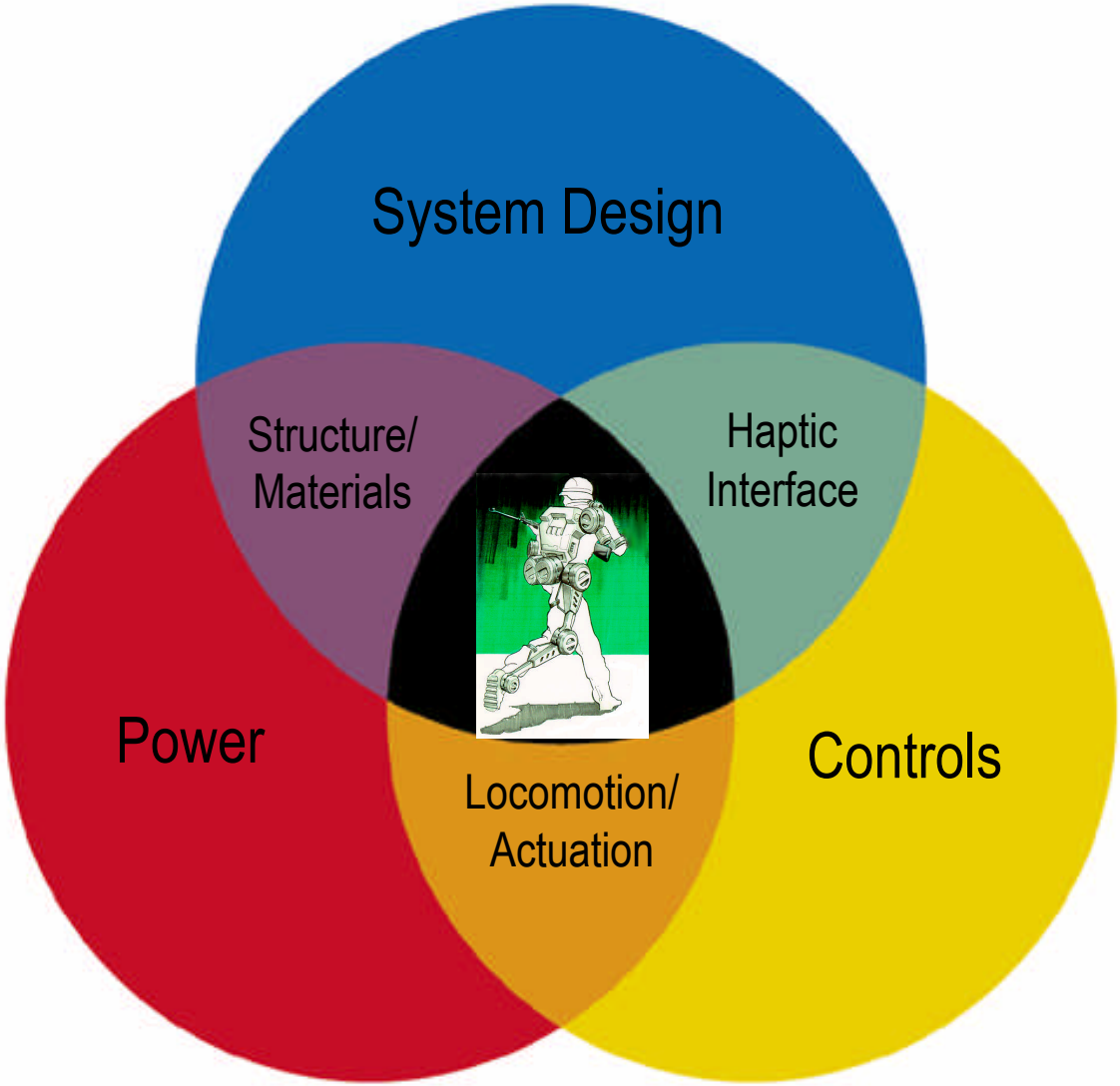
Technical Objectives

Design, develop and test technical approaches to exoskeletons to enhance the performance of combat personnel
Develop novel energy efficient actuation schemes
Formulate approaches for active control that sense and enhance human motion
Demonstrate machines for highly agile locomotion and enhanced strength

Deliverables

Integrated Power/Actuator Systems
Haptic Interfaces
Control Systems for Wearable Machines
Human Strength Amplification
Machine Assisted Locomotion
Load-bearing Machine Assisted Locomotion
Full Multifunctional Exoskeleton

Exoskeleton Requires Multidisciplinary Approach



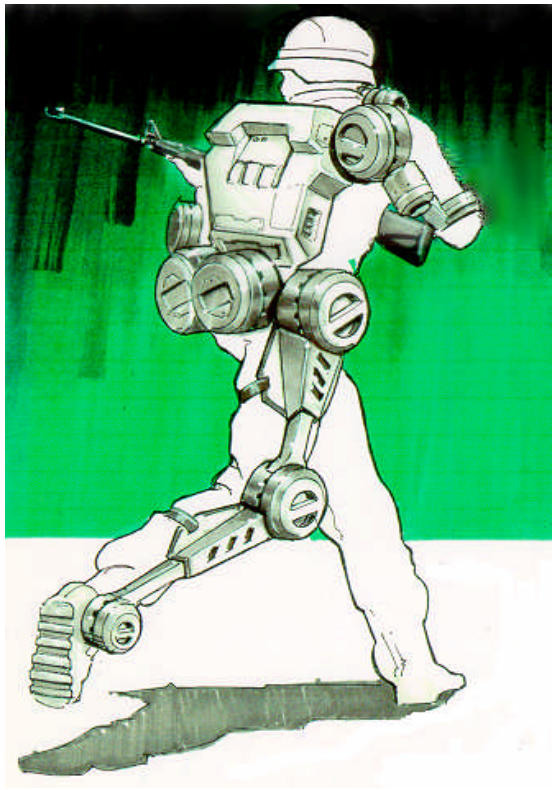
BAA Teaming Suggestions

Remember -- Each BAA and Program is a separate entity and is run by its own Program Manager (PM)

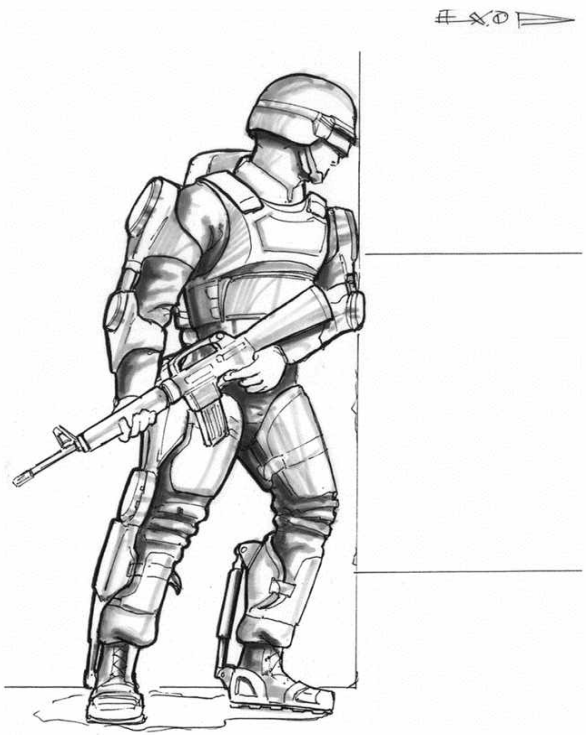
Team where appropriate:

- in order to ensure quick development and exploration of key issues to the program
- to bring disparate technologist together to address multidisciplinary issues to work toward a common solution
  - don't force fit partners
  - know your own weaknesses as researchers and find people to augment your talent
- to develop project for transition to commercialization and/or military

Exoskeleton Applications - Examples



Enhanced speed and mobility



Armored Soldier

Benefits and Impact

Increased payload

⇒ fire power, ballistic protection, supplies,...

Increased strength

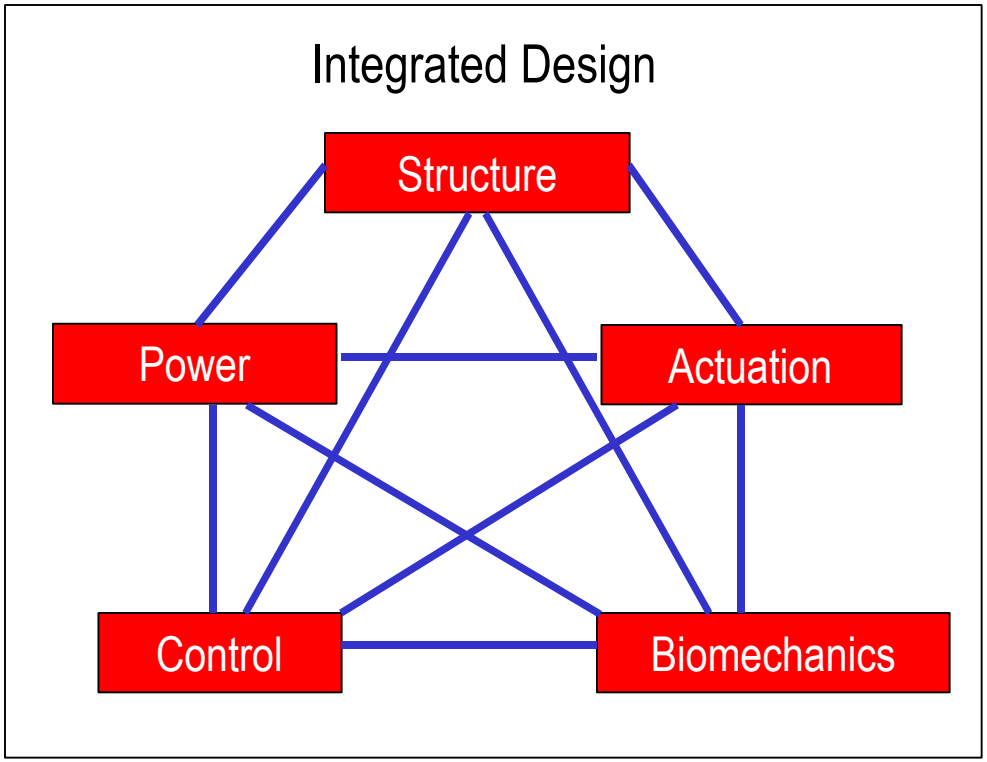
⇒ larger caliber weapons, obstacle clearance,...

Increased speed and extended range

⇒ enhanced ground reconnaissance and battlespace dominance

Increased unit survivability and lethality

Challenges



Structure

- Light-weight, strong, flexible materials
  - multifunctional, composites
- Ballistic protection capable, armament capable

Power

- High energy density fuel
- Quiescent power consumption near zero
- Quiet (stealthy)

Actuation

- Efficient, quiet, integration w/ power and energy source

Control

- Sensing, feedback, hierarchical approaches, highly nonlinear sys
- Haptic interfaces

Biomechanics

- Agility issues, ergonomics, human factors

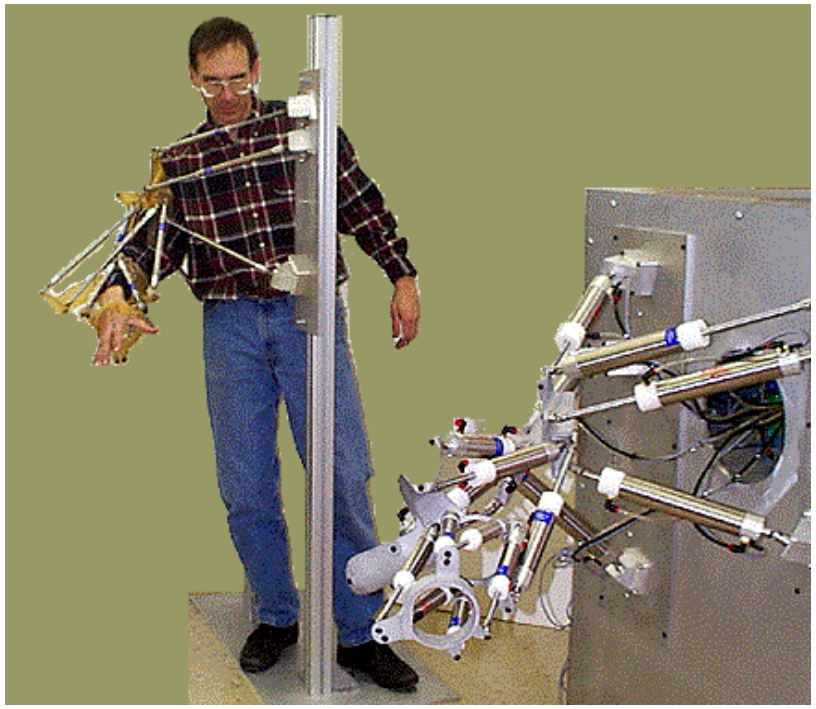
System Design

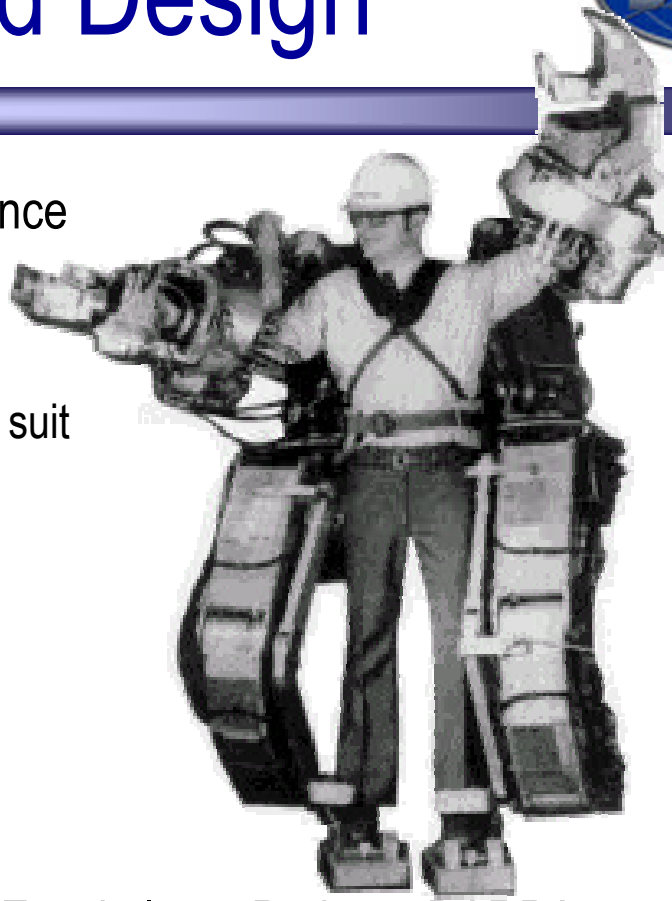
- Passive approaches to fully active

Structure and Design

Previous Attempts at Enhancing Human Performance

- Hardiman, 1965
- General Electric w/ military funding
- 1,500-pound, 30-DOF, hydraulic & electric full body suit





Early Exoskeleton Project - DARPA

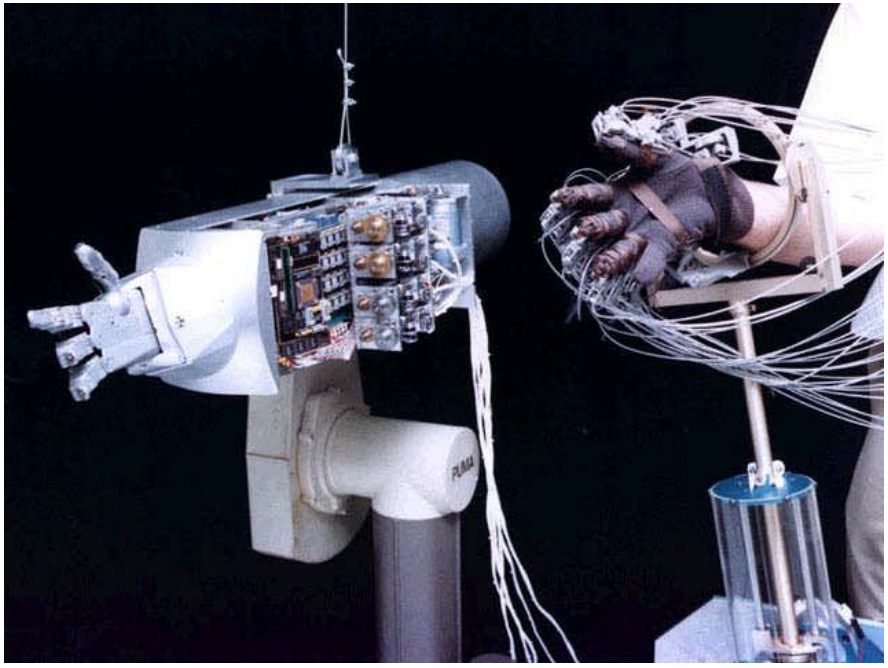
- Proposed use of Magnetic Rheological fluid for actuators
- Pilot study - proposed for logistical support; non-combat

Ordinance loading demo for aircraft at Oak Ridge National Labs

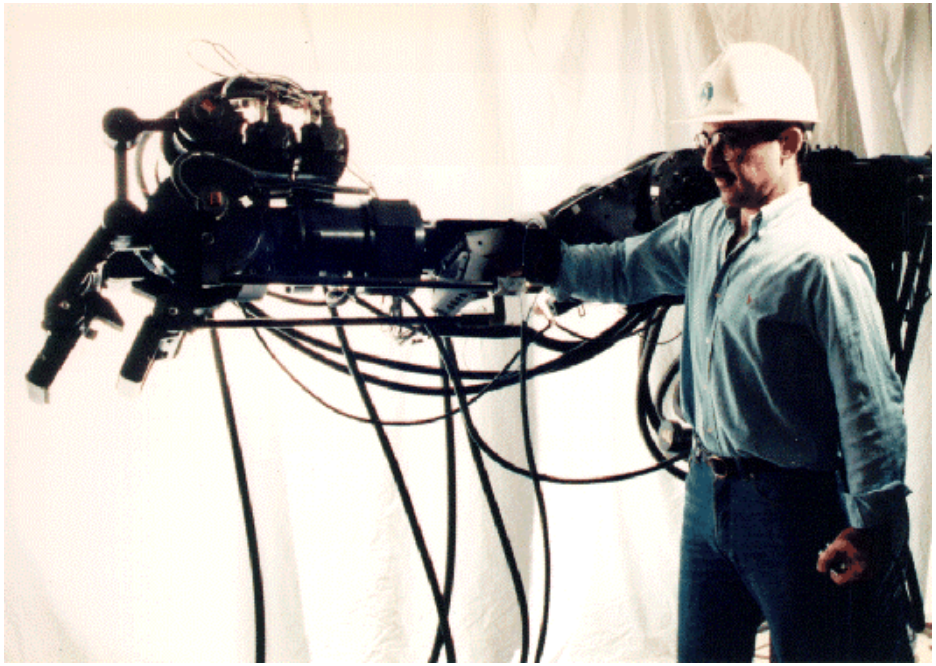
Controls/Haptic Interfaces

Tele-Medicine and Tele-presence

- Developed for the military and the space program



NASA Jet Propulsion Laboratory



Kazerooni, UC Berkeley s Human Engineering Laboratory, early 90s

- Built an experimental 6-DOF hydraulic extender
- Need to examine power issues

Biomechanics Technology

- Gravity Compensation and Force Modulation System Control
- Soft Tissue Interface
  - Distributed sensing: Can we develop a quality man-machine interface with only point sensors?
  - Neuro-mechanical responses
- Understanding and Developing Systems to Capture Human Motion and Mechanics
- ISMS - Robot Supporting Human
  - Man-machine interfaces
  - Controls and haptic interfaces

Energy Comparison for Pack-Load Assistance

Type	Energy Source	Prime Mover	Conversion Efficiency (%)	Fuel Specific Energy (watt-hr/kg)	Prime Mover Specific Power (watt/kg)	Fuel Weight for 130 watt-hr @ 65 watts (kg)
Electric	Lithium Battery	Electric Motor	80%	200	1000	0.7
Internal Combustion	Hydrocarbon Fuel	Internal Combustion Engine	30%	13,000	1000	0.1
Compressed Gas	Compressed Liquefied Gas	Pneumatic or Hydraulic Motor	80%	55	2000	2.4
Solid Elastic Material	Compressed Spring	Spring	100%	40	NA	3.2
Fuel Cell	Compressed Hydrogen	Electric Motor	20%	5600*	200	0.5

* H_2 33,000 watt-hr/kg x .017%

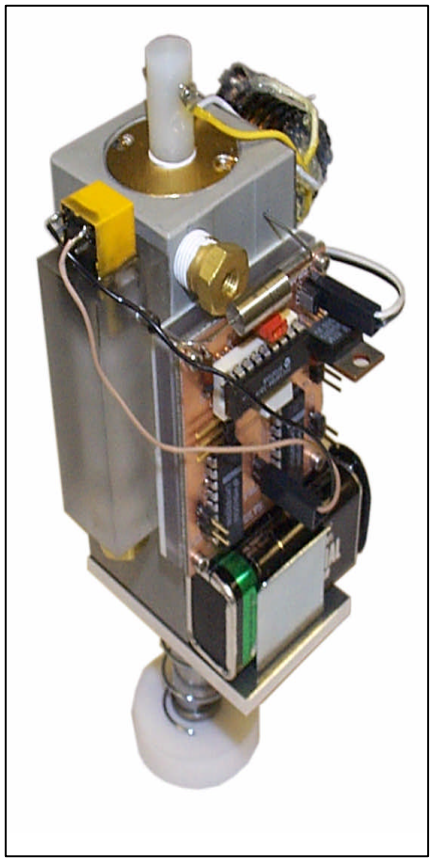
Consider a 10 km @ 5 km/hr
- 75 cm stride
- 5 cm c.g. change, level terrain

Power Energy Required
- 130 watt-hours @ 65 watts

Parameters point to chemical energy as a power source
- unit refuel possible; fuel already in logistics supply train

Integrated Power/Actuation Systems

- Chemo-mechanical actuators for locomotion
  - MEMS or small meso-manifold to control fuel flow, air mixing
  - Mesoscale actuation of valves and fuel via smart materials
  - Feedback to control amount of fuel combustion
- May need to utilize direct conversion of chemical bond energy to mechanical work
  - e.g., SANDIA Hopper fuel combusted in 2 mg burst, generates ~1 meter jumps



SANDIA-Hopper

EHPA Issues

- Challenge: Fundamentally change the way we think of a controlled, engineered system
  - structural design - multifunctional in addition to being load bearing
    - structure could be integrated with power (electric & hydraulic), information buses, and integrated connectivity
- Devices and machines that augment human capability
  - sense human motion and react to it
    - controlled machine that extracts energy from a supply and delivers it in a controlled fashion to aid the soldier
  - well balanced machine, bio-inspiration from human locomotion
    - pulsed energy in a oscillatory fashion, generating a gait

Energy, Power and Actuation!!!!!

- Can we devise of actuation schemes that rely on high energy dense fuel sources; butane, diesel, etc.?
- How do we efficiently convert power from an energy source, e.g., chemical fuel?
  - Can new power technologies such as fuel cells meet mission requirements?
  - Can we devise new actuation technologies relying on MEMS, LIGA, and Smart Material components to precisely control fuel consumption, and generate mechanical power from consumed fuel supply?
  - Can we accomplish this feat with traditional actuators? Must we design new types of actuators?

Human & Machine Interface

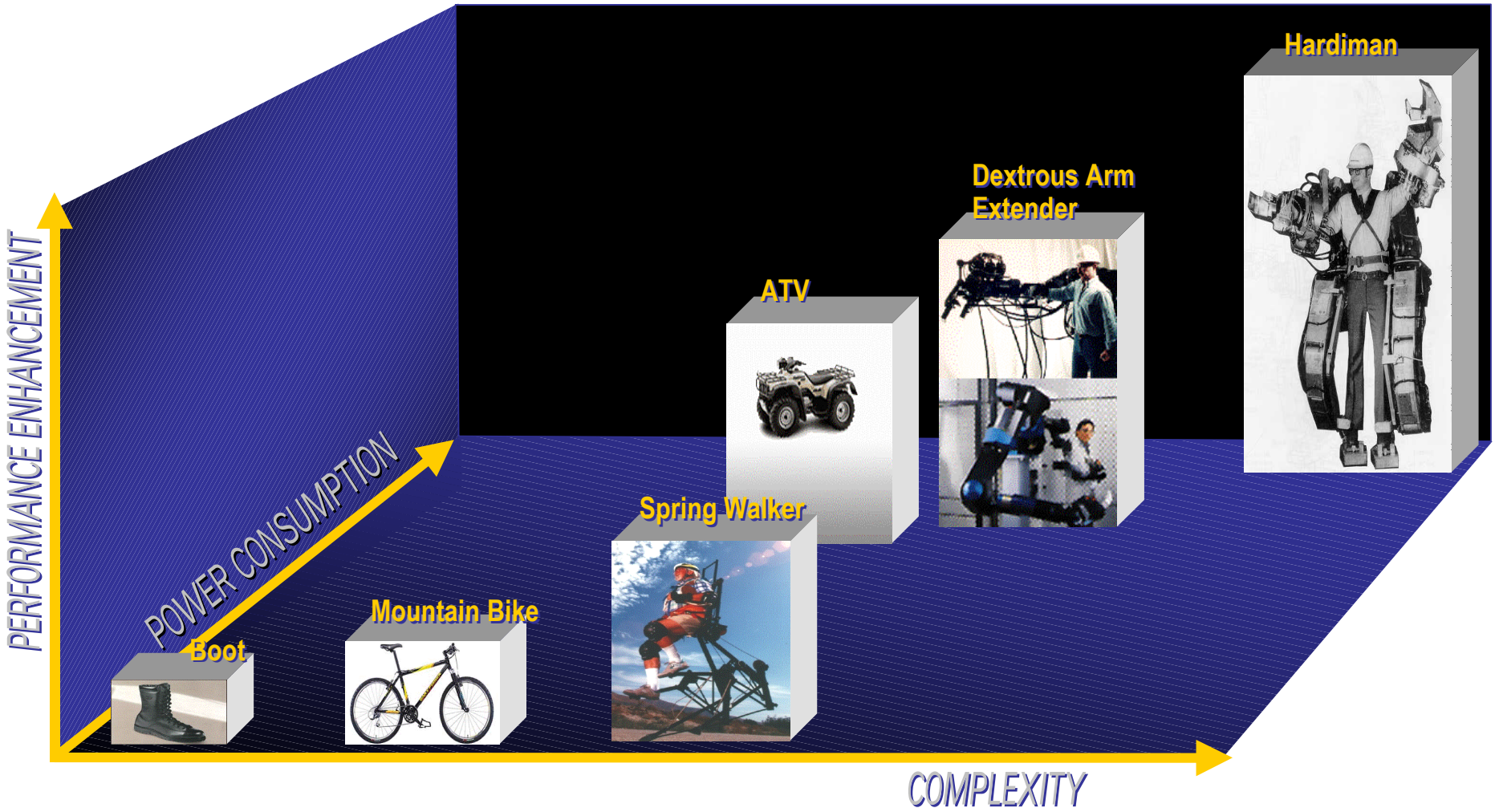
Haptic Interfaces and Controls

Can we build controllers that allow machines to follow human motion and enhance it? Can we do this and minimally impact any adverse effects on human agility, and, in many ways, increase soldier abilities?

Can this machine operate solely on touch from the operator or will it require more complex sensing?

Controllers need to be stable, robust, and safe over a wide range of movements and initial conditions?

Device and Machine Design Space



Some Observations

- Devices must be developed, concurrently designed with the power plant
  - power must be sufficient for significant duration, satisfying a large number of missions scenarios
  - managed power
- Unconstrained development, not bound to logistics fuel
  - radically new capability
  - no set of specifications

Observations cont d

Human factors need to be considered

expect to be asked to take your work into the field

More thoughts on teaming

the same duration?

Fund the people who are doing the work - uneven funding

Ask for what you need

Proposal Questions

We constantly ask our Technical Directors/Program Managers:

- What are you trying to accomplish?
- How is it done now, and with what limitations?
- What is truly new in your approach which will remove current limitations and improve performance? By how much?
- If successful, what difference will it make?
- What are the mid-term, final exams or full scale applications required to prove your hypothesis? When will they be done? *Decision points and time*

Transitions...

- How much will it cost?

Program Execution and Major Milestones